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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 372

FIRST EXPERIENCES WITH THE ROTATING LABORATORY

By L. Prandtl

From "Naturwissenschaften," May 7, 1926, (Vol. XIV)

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FIRST EXPERIENCES WITH THE ROTATING LABORATORY.*

By L. Prandtl.

In the address at the dedication of the "Kaiser Wilhelm Institut für Stromungslehre" (Emperor William Institute for Flow Research) published in "Naturwissenschaften," No. 16 of this year (1926), a rotating room was included in the enumeration of the apparatus to be provided. This was completed a few months ago and was first used for observations on the behavior of a man in an inclosed rotating space. To our dismay, there were manifestations which seemed to put in doubt the availability of the rotating room for the purpose of experiments on the flow of water and other mechanically interesting phenomena. In short, it was not only so difficult to maintain our bodily equilibrium, that all changes of position were extremely fatiguing, but we were genuinely seasick, so serious was the result of the disagreement of the visual space with the inertia space, as experienced by the organ of equilibrium. It is very remarkable that we did not notice any of these phenomena in the preliminary experiments, before the walls of the rotating room were closed. Then we saw the non-rotating environment as from an ordinary carousel, and the impressions of the equilibrium organ were in

* "Erste Erfahrungen mit dem rotierenden Laboratorium," from "Naturwissenschaften," May 7, 1926, (Vol. XIV), pp. 425-427.

harmony with what we saw.* Aside from the usual dizziness or vertigo caused by long-continued rotation, there were no further disturbances. Moreover, the systematic continuation of the experiments and the analysis of the sensations produced by the various kinds of motion soon indicated the probability of a "hygiene of the rotating room." It consists chiefly in the fact that all turning and inclining of the head must be avoided or made very slowly. Subsequently, in fact, by conforming to this rule, we were able to stand three times as great a rotation speed as that which formerly made us sick. This speed was 40 R.P.M. and the diameter of the rotating room was about 3 m (10 ft.). We were held against the wall by a centrifugal force 2.4 times that of gravity and found it difficult even to extend an arm. By holding our heads still, we experienced no further discomforts, however.

The sensations produced by moving the head may be described somewhat as follows, it being assumed that the room rotates in the direction of the hands of a watch lying on the floor. Tipping the head to the left then gives the impression that the floor in that direction slopes downward, while tipping the head to the right gives the impression that the floor slopes upward.

*Dr. Betz informs me that he found on a trip in a submarine, that strong rolling motions of the boat made him sick when he was inside, but that he soon felt better when he went on deck and saw the horizon. The disagreement between the visual space and the inertia space, although not the only cause, seems therefore to be one of the chief causes of seasickness. This is confirmed by reports of seasickness on airplanes.

On tipping the head forward, the floor seems to move toward the left and on lifting the head it seems to move toward the right. (These phenomena are all reversed when the room is rotated in the opposite direction.) If these motions of the head are made slowly back and forth, one receives the impression of being in a large swing which swings forward and backward when the head is tipped sidewise and to the left and right when the head is nodded forward.

The sensitiveness for variations in the rotation speed of the room is also very pronounced. When the speed is increased, one has the impression that the room is rotating, although he can see nothing to judge the motion by. Subsequently this impression vanishes and he has the feeling that the room is at rest, so long as he does not try to move. When the speed is decreased by braking, he has the impression that the room is rotating in the contrary direction to what it was before. If he leaves the room after stopping it quickly, he feels the same dizziness that he would after long-continued rotation on his feet.

The sensations all have a common source. It is well known that when we turn the head, with or without turning the whole body, all the surrounding objects still appear at rest. This is due to the action of the equilibrium organ (semicircular canals of the inner ear). While rotating to the right, the eye turns to the left with the same angular speed (and conversely).

In longer turns, after a certain angular distance, the eye jumps back to the right and then continues turning to the left. Thus the eye fixes itself in turn on certain stationary points and thus produces the impression that the environment is at rest. This motion of the eyes takes place in the dark and even when the eyes are shut. In the rotating room, when it is starting to rotate in the direction of the hands of a watch, the eyes, influenced by the equilibrium organ, glide along the wall toward the left and thus produce the impression that the wall is moving toward the right. At every backward jump of the eyes, however, they see the same portion of the wall in the same direction, so that the impression of turning becomes confused with that of rest, just as in ordinary vertigo. The ocular movements gradually cease and there remains an impression of rest. When the brake is applied, the change in the rotation speed gives the equilibrium organ a new impulse (though in the opposite direction) which again causes a motion of the eyes and the impression of rotating backward.

The effect of tipping the head can be explained on the same principle and, in fact, the peculiar phenomena described above are of the same kind as the backward rotation in braking. The organ of equilibrium, which does not react to the rotation speed, but only to its temporary changes, gradually "forgets" the existence of rotation, when long continued, and therefore senses variations in the rotation as independent rotations. It

is well known that we can compose rotation speeds the same as forces, by representing the rotation speeds by lines parallel to the axis of rotation. On inclining the head to the left, (for example), the "forgotten" rotation A (see the figure) reacts so that it seems stationary with relation to the organ of equilibrium and hence to the head, although the actual rotation has the position B. The rotational difference C between B and A is actually perceived while tilting the head and, of course, the tilting motion also. Only the normal sensations are, however, awakened by the reaction of the equilibrium organ to the motion of the head. On the contrary, the rotation C, which continues after the inclined head becomes stationary, is very disturbing and continues until it is again "forgotten" among the impressions coming through the eyes and which do not correspond to the rotation C. In detail, the following is what happens. The rotation C, which leads downward in front, causes an upward motion of the eyes and hence the impression of the sinking of the floor. Similar reasoning, in the forward nodding of the head, etc., applies to the other phenomena described.

If, in nodding the head forward, one looks horizontally ahead, he notices very little, outside of a disagreeable disturbance of the sensation of equilibrium, while the reaction is very strong if he looks downward. An analysis of the motion of the eyes renders this quite comprehensible. The eyes cannot follow a wheel revolving slowly around the line of vision as its axis,

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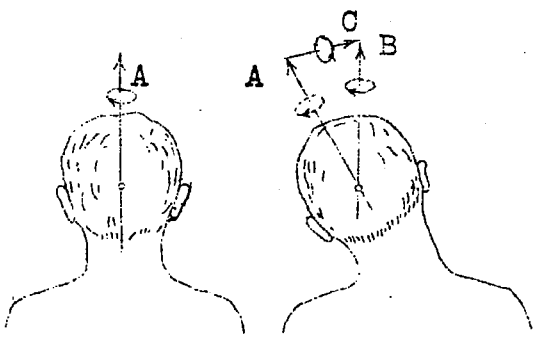
so as to produce the impression that the wheel is stationary. There is therefore no compensative motion of the eyes for a turning of the head around the line of vision and consequently, no illusion results in nodding forward in the rotating room, whereby the rotation axis C is directed forward. It is very probably there, however, when the line of vision makes an angle with the axis C.*

In conclusion it may be remarked that the variation of the resultant line of gravity (from gravity and centrifugal force) was not felt so strongly as might be expected. When standing eccentrically, one noticed plainly an inclination of the whole room in the anticipated direction, though much less than the inclination of the resultant force, evidently due to the contrary effect of the visual impressions. The impressions produced by the physical effects on the members of the body, especially the ones caused by the deflecting force (Coriolis force), are exactly what the laws of physics would lead us to expect, although somewhat surprising when observed in one's own body, as, for example, that we can rotate toward the left more easily than usual, but only with great difficulty toward the right (when the room

*Subsequently, a very interesting experiment has been tried on two persons who, as the result of sickness, have only one semicircular canal capable of functioning, in which it was established that such persons experienced in the rotating room neither the above-described disturbing sensations nor any other discomforts. It follows, therefore, that there is probably a reciprocal action of the two semicircular canals involved in the production of the phenomena described. (We do not wish, however, to assume that the remaining equilibrium organ of the two persons is no longer of full value, as we were not able to investigate it more thoroughly.)

is rotating in the clockwise direction).

It is very much to be hoped that the rotating laboratory, after we have learned how to deport ourselves in it, will serve its real purpose of investigating the laws of flow and will yield us a rich harvest of results. The beginnings have already been made. I hope to be able to give you later a further report in this connection.



Supplementary Remarks

On the occasion of delivering a lecture on this subject before "Der Niedersächsische Gauverband der Deutschen Physikalischen Gesellschaft," my attention was called to the fact that observations on the behavior of a person in the rotating room were described by Ernst Mach some fifty years ago. In fact, I found in his "Grundlinien der Lehre von den Bewegungsempfindungen," Leipzig, 1875, pp. 23-31, nearly all the observations I

have just reported. Mach employed a chair, mounted in a vertical frame, so it could be tilted or rotated, which he inclosed in a paper box in order to eliminate the effect of external objects on the visual impression. Mach mentions that similar experiments had already been described by Purkinje in 1826 ("Physiologische Beobachtungen über den Schwindel," 10th Bulletin der Naturwissenschaftlichen Sektion der Schlesischen Gesellschaft," p. 35, Breslau, 1825; also 12th Bulletin, 1826, p. 1).

Translation by Dwight M. Miner,
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